

EXPLORING HOW FUNCTIONAL IMPROVEMENT IS RELATED TO
INTERACTION BETWEEN CHILDREN WITH CEREBRAL PALSY AND HORSES
DURING HIPPO THERAPY: A PILOT STUDY

A Thesis

by

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ABSTRACT

Hippotherapy (HPOT) refers to how occupational therapy, physical therapy and speech-language pathology professionals use evidence-based practice and clinical reasoning in the purposeful manipulation of equine movement as a therapy tool. There is limited scientific, evidence-based research to support the effects of HPOT, hence there is a need for such equine-assisted therapy for individuals with cerebral palsy (CP). This pilot study evaluated the impact of HPOT between children with CP and horses in terms of kinetics. The participants were 4 children with CP between 3 and 12 years of age. Eight 20-minute sessions of HPOT treatments were conducted, with data collection on days 1, 4 and 8. Functional mobility was measured using the Timed Up and Go test for 3 subjects and 10-Meter walk test for 1 subject, all performed before and after HPOT on data collection days. Six Inertial Measurement Units (IMU) devices were used to measure the acceleration of the children and horses during the HPOT. The IMU sensor data was analyzed using fast Fourier transformation (FFT) and cross-correlation with a time shift. The study is to determine the rationale behind the success of HPOT. The results show that as the therapy progressed, the subjects demonstrated a significant decrease in the time required to complete the functional mobility tests and improved in the ability to synchronize with the horse's movement in the up-and-down direction. In conclusion, this study provides evidence that HPOT can be leading to improved functional mobility for children with CP as evidenced by the positive interaction between the movements of the children with CP and the horse. Future work includes analyzing data in other planes of movement and evaluating causality between improved functional mobility and positive interaction.

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1. BACKGROUND AND INTRODUCTION

1.1 Cerebral Palsy (CP)

Cerebral palsy (CP) is an umbrella term that refers to a brain injury or malformation which affects a person's ability to move [1]. In the United States, approximately 800,000 people, including children and adults have at least one symptom of CP and around 10,000 babies are born each year with CP. Overall, one in 323 children in the U.S is diagnosed with CP [2]. Even though there are many children diagnosed with CP, there is no known cure. CP is caused by damage to the motor control centers of the developing brain, which can happen while the brain is maturing. More than 70% of children with CP have spasticity, a condition in which certain muscles appear stiff and tight [1].

There are a variety of symptoms of CP which affect the level of severity [3]. Some common signs of CP may include: i) problems with movement on one or both sides of the body, ii) stiff muscles, iii) exaggerated or jerky reflexes, iv) involuntary movements or tremors, v) lack of coordination and balance, vi) drooling, vii) problems swallowing or sucking, viii) difficulty with speech (dysarthria), ix) seizures, x) contractures (shortening of muscles), xi) delayed motor skill development, xii) incontinence. Among them, the most significant problem in children with CP is the lack of postural control and dynamic balance related to functional mobility, which affects their daily lives [4].

1.2 Hippotherapy (HPOT)

A variety of therapies exist for treating individuals with CP, and many designed to address specific symptoms of the disorder. Recently, hippotherapy has been shown to have

a positive impact on children with movement disorders, including CP [5]. HPOT has become increasingly popular for persons with CP as it is believed to have the potential to treat a variety of concerns experienced by this population. It is believed that HPOT has the potential to treat various concerns persons with for cerebral palsy and has become increasingly popular for patients with CP [6]. According to Equine-Assisted Growth and Learning Association (EAGALA), there are more than 600 HPOT programs designed for patients with a broad range of psychological and physical conditions and 60,000 clients were served worldwide in 2018 [7].

HPOT is a form of physical, occupational and speech therapy treatment strategy using the characteristic movements of a horse [8]. HPOT involves not only riding a horse but also interacting with a well-trained horse (e.g. grooming, petting, talking). This therapy has the potential to improve the patient's: i) overall strength, ii) trunk and core strength, iii) gross and fine motor control, iv) balance, v) posture, vi) muscle tone, for both hypotonia and hypertonia, vii) the ability to give and receive visual cues, viii) sensation, ix) communication skills, x) social skills, xi) confidence and self-esteem [9].

Benefits of hippotherapy may result in building trunk and head stability, which are fundamental components of functional mobility, and is commonly used for children with neuromuscular disabilities [10, 11]. In hippotherapy, the movement of the horse offers a variety of challenges to the rider, which may facilitate improved muscle activation, joint stability, weight shift, and postural equilibrium responses in children with cerebral palsy [12]. The movement of the horse's gait at a walk provides dynamic, repetitive opportunities for a patient to develop, practice, and refine motor skills [5].

2. LITERATURE REVIEW

Previous studies have described the benefits of the movement of horses for children with CP, including improved gross motor function, dynamic balance, and trunk postural coordination. In general, researchers employed the Gross Motor Function Measure (GMFM) and Pediatric Evaluation of Disability Inventory (PEDI) as outcome measures for children with CP because both are recognized as reliable and valid tools used to assess gross motor function and functional mobility [13]. The HPOT intervention for children with CP typically focused on maximizing potential through improving gross motor skill and functional mobility [14]. According to Graham et al [15], functional mobility is the manner in which a person moves within the environment to perform daily activities, including interacting with others. Walking performance is a commonly used by health professionals as a measure of functional mobility.

For instance, Park et al [16] used GMFM and PEDI- Functional skills scales (FSS) to evaluate the effects of HPOT on gross motor function and functional performance of children with CP. This study was designed with large sample sizes: 34 children in the group that received HPOT and 21 children in the control group. After 8-weeks HPOT treatment, significant improvements in walking, running, and jumping of GMFM and in self-care, mobility, and social functioning of PEDI were shown in the HPOT group, but not in the control group. These results demonstrated the positive effects of HPOT on gross motor function and functional performance of children with CP.

Another study designed to enhance the understanding of the effects of HPOT was conducted by McGibbon et al [17], and focused specifically on lower extremity adductor

muscle activity using surface electromyography. The asymmetric adductor muscle activity of children with CP might cause reduced hip range of motion and possible dislocation, resulting in poor dynamic balance and inefficient walking [18]. The researchers examined the relationship between the improvements in adductor symmetry and functional mobility. Absolute differences in mean EMG values between the left and right sides of individual muscle groups during each task were calculated and recorded as asymmetry scores. After 12 weeks of weekly HPOT, 4 out of 6 subjects showed improvement in adductor muscle symmetry during walking and all 6 subjects improved in the GMFM scores. The study indicated HPOT might have improved adductor muscle symmetry and functional mobility, but improved adductor symmetry alone did not fully explain the increase in GMFM scores for all subjects. Two subjects showed improvement in their overall motor skills even though their adductor symmetry did not improve over time. The positive changes in functional skills might have occurred due to multiple factors related to postural control and dynamic balance [17].

The above studies showed the positive outcome of HPOT. However, they could not explain the influence of the horse's movements on the rider's body. Some researchers attempted to examine the influence of the horse's movement on children with CP during HPOT using kinematics.

It can be hypothesized that additional investigations may result in better performance. One study that looked at the long term effects of HPOT was conducted by Shurtleff et al [10]. The researchers investigated changes in head and trunk stability in a child with CP over 36 weeks of weekly HPOT. In this study, video motion capture allowed precise

tracking of kinematic trunk movements during HPOT sessions. The results demonstrated a reduction in the subject's average anterior-posterior movement after 12 weeks of HPOT compared to Pre-HPOT. However, the result did not show any improvement after 12 weeks of HPOT. A significant limitation of this study was the extremely small sample size ($n=1$) which was not enough to draw a conclusion about the impact of HPOT on children with CP.

Haehl et al [19] examined the influence of HPOT on the kinematic performance of children with CP. It suggested the existence of a kinematic relationship between the patient and the horse during HPOT. Also, it demonstrated that a rider showed a movement pattern in response to the horse's movement. The study used a 60-Hz camcorder set up in an indoor arena to collect kinematic data. Markers were used to calculate the children's upper trunk, lower trunk and the horse's caudal angles shown in Figure 1. The changes in trunk angles of the children with CP per horse stride exhibited smooth movement patterns over time and notably, the angles of children's upper and lower trunk followed similar trajectories in response to the horse's movement. However, the trunk angles alone could not fully explain the increase in trunk control because there exists the possibility that the participant use his/her trunk and arm muscles together to facilitate postural control. The primary limitation of this study is the lack of explanation of how the movements interacted during horse riding.

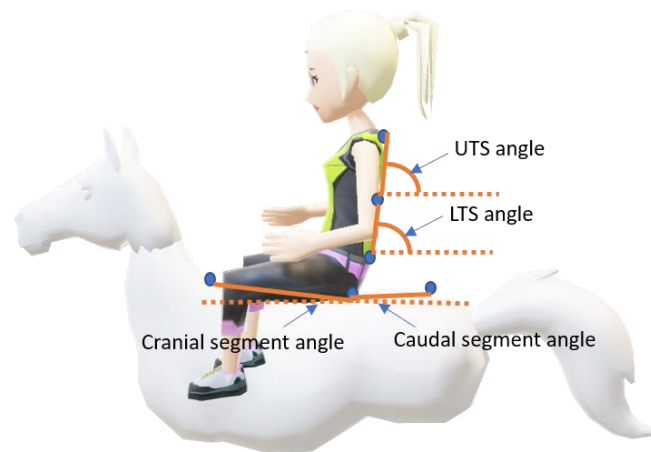


Figure 1: Measurements of postural orientation of the subjects

Similar to the above study, MacPhail et al [20] determined whether the patient would react to the horse's movement while riding kinematics. The study conducted a kinematic analysis of the lateral trunk movement of the patient with respect to the movement of the horse. Specifically, the researchers used kinematic analysis to plot the average lateral displacement of the riders' trunk relative to the movement of the horse during each stride. The study compared six children with CP to children who were typically developing. The displacement angles of the subject's trunk and horse's pelvis were calculated from the data to determine the movements of the rider and horse in Figure 2. The markers allowed the evaluation of the lateral movement of the trunk. All nondisabled children showed a similar and steady pattern of trunk movement compared with the horse's movement. On the other hand, children with CP responded inconsistently and their movement appeared poorly coordinated to the horse's pelvic movement. The results demonstrated that children without disabilities produced a consistent pattern of trunk movement in response to the horse's pelvic movement and the synchronization between the movements of the children

without disabilities and horse occurred during HPOT sessions. On the other hand, the synchronization between the movements of the children with CP and the horse was minimal during HPOT sessions.

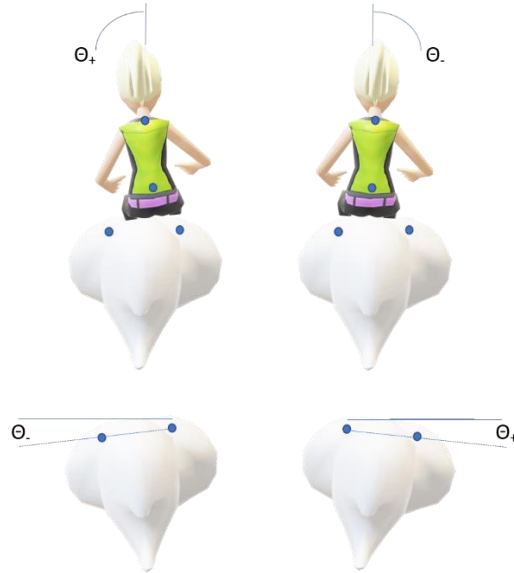


Figure 2: Joint Marker Placement and angle definitions

In addition to kinematics, other types of data have been used to analyze the impact of HPOT on children with CP. Uchiyama et al [21] performed a three-dimensional analysis of acceleration data to evaluate the similarity between the movements of human walking and horse walking, based on the hypothesis that the horse's pelvic movement during HPOT is similar to the human pelvic movement while walking. Normal walking acceleration data for humans and horses for 3 min, respectively were collected, and the stride-phase data was generated according to the walking cycle. The data was converted into its corresponding frequency domain. The results have shown that the frequency peaks of human walking corresponded with those of horse walking. Especially, the frequency

spectra of human walking and horse walking in the Z-axis (up and down) were more correlated than in the X and Y-axis. It might imply horse walking gait during HPOT offers the stimulation of a walking exercise as a normal human does.

When conducting the literature review on the effects of HPOT on children with CP, no studies were found that have focused on the kinetics-related interaction between the rider and the horse during an HPOT session. Considering the concept of the kinetics, whenever there is an interaction between two objects, there is an interaction force upon each other [22]. Therefore, interaction should be examined through kinetics, along with kinematics. Even though acceleration data is considered as kinematic data, it was used for kinetics because acceleration represented force normalized by mass through the equation that force is mass times acceleration. This study focused on the interaction between the rider and horse in term of kinetics, not kinematics.

3. MOTIVATIONS FOR THE RESEARCH

Previous research on the effects of HPOT on CP emphasized the importance of providing evidence to support the benefits of HPOT. There have been various attempts by researchers to examine the positive influence of HPOT on CP and the interaction between movements of patients and horses during HPOT. Most studies on the influence of HPOT on CP focused on the functional performance of the participant, not on the mechanism of how the movement of the horse affects the movement of the children with CP. A few researchers provided kinematic evidence-based effects of HPOT but the fundamental mechanism in the kinetics of HPOT has not been fully elucidated. Specifically, the relationship between the kinetic changes during HPOT and functional performance need to be examined.

Another factor that prompted the researchers to look into kinetics of HPOT was the growing demand for Equine-Assisted Therapy (EAT) as seen with the establishment of many such programs world-wide. Many believed it to be a successful strategy for helping children with CP to gain skills and improve quality of life. Therefore, it has become important to provide quantitative evidence to demonstrate the positive effects of HPOT on individuals with CP.

In sum, there is a dearth of research on the kinetic relationship between the movements of children with CP and horse during HPOT. Besides, there is a need to enhance the relevance of HPOT to the improvement in functional mobility and positive interaction between horse's and patient's movements.

4. RESEARCH GOAL AND OBJECTIVE

The long-term goal of this thesis was to identify the determinants of the positive effects of HPOT on children with CP. It has been stated that most studies on HPOT focus on trunk stability, posture, and pelvic mobility for improvement in gait and balance, not on the interaction between patients and horses. There is a need for more reliable research on the kinetic relationship between the movements of children with CP and the horse during HPOT. It is believed that this study would be helpful not only for therapists and medical professionals, but also for patients with CP.

This objective of the study was to observe changes in the functional mobility of the subjects and kinetic changes during HPOT, over time. This thesis aimed to monitor the improvement in functional mobility as therapy progressed. Also, this study aimed to observe how the movements of subjects and horses interact during HPOT. The changes in the interaction between the movements of subjects and horses over time were observed for the study.

Based on these objectives, the following hypotheses for the study were formulated:

- I. The functional mobility of children with CP would improve as the number of HPOT sessions increased.
- II. In terms of the interaction, the movements of the children and the horses during the therapy would become more correlated as HPOT sessions progresses.
- III. The movement of children in HPOT would follow the movement of horses.

5. MATERIALS AND METHODS

Prior to beginning the study, ethical approval was obtained from the Institutional Review Board at Texas A&M University (2018-0064, 2018-0028) and the Animal Use Protocol. Four children were recruited by a physical therapist through multiple channels , including but not limited to, reviewing the wait list for applicants of the Texas A&M University Equine-Assisted Activities and Therapy program. Parents signed informed consent, liability, and photo release forms. Subjects in the study consisted of 1 boy and 3 girls, ranging in from 3-12 years and diagnosed with spastic CP. The inclusion criteria for children with CP were as follows: i) age 3 to 12 years, ii) gross motor function classification system (GMFCS) level I, II, III and iii) the ability to signal pain, fear, or discomfort. The exclusion criteria were as follows: i) botulinum toxin treatment, orthopedic, or neurosurgery in the previous 6 months, ii) severe intellectual disability, iii) scoliosis, and iv) poor visual or hearing acuity. The first, second, and third subjects had spastic hemiplegia CP, which affects only one side of a person's body, and the last subject had spastic quadriplegia CP, which affects all four limbs, the trunk, and the face [23]. The information of subjects is shown in Table 1.

Table 1. Profiles of the subjects in this study

Subject #	Type of Spasticity	Sex	Age(y)	Height(cm)	Weight(kg)
1	Hemiplegia	Female	3	87.6	12.3
2	Hemiplegia	Female	12	128.3	23.4
3	Hemiplegia	Male	4	N/A	18.6
4	Quadriplegia	Female	10	127.0	22.7

Before performing tests, a full explanation of all procedures was provided not only to children but also to parents or caregivers.

All testing processes were designed to examine the objective and hypotheses for the study. All tests were conducted under the direction of the physical therapists or equine specialists and were recorded on video for data analysis. The first three subjects received weekly therapies for 8 weeks. The last subject received 8 therapy sessions in 5 weeks because she felt ill and due to poor weather conditions. All subjects received no other physical therapy to avoid outside influences that may have affected the functional performance of the children in the study. As shown in Figure 3, there were 3 data collection sessions in 8 weeks sessions. None of the subjects dropped out of the study.

Session	1st	2nd	3rd	4th	5th	6th	7th	8th
Subject 1								
Subject 2								
Subject 3								
Subject 4								

Figure 3. Timetable for HPOT and data collection

Data collection sessions were designed to observe the changes in functional mobility, with measurements taken before and after HPOT sessions. Data collection sessions involved 3 parts: i) functional mobility tests before HPOT, ii) HPOT, and iii) functional mobility tests after HPOT. Figure 4 represents the overall flow of the experiment in the study.

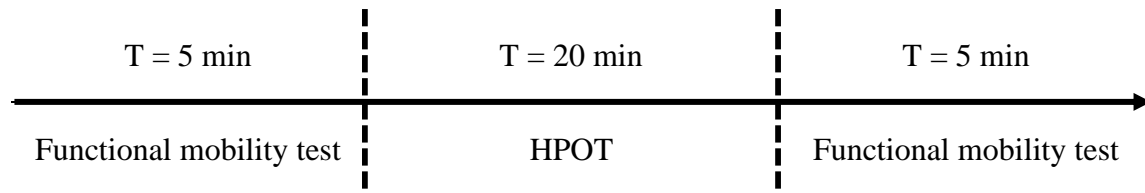


Figure 4. Flowchart in data collection session

5.1 Intervention

HPOT was performed at two different PATH (Professional Association of Therapeutic Horsemanship) International premier accredited centers, as well as at TAMU Parsons Mounted Cavalry (PMC). Ride on Center for Kids (ROCK) is in Georgetown, TX and TAMU Grimshaw Family Equine Therapeutic Program which works out of Freeman Arena is in College Station, Texas. Information on size and use of the horse arena is shown in Table 2. Considering the difference in size between the arenas, the trajectories of the horse and walking distances were controlled as much as possible between the centers.

In HPOT, the subjects were not required to control the horse. The horses were all trained for the riding programs and controlled by a horse handler who was accompanied by a therapist and an assistant. Horse walking speed in the study was 1.03 m/s, which is similar to the average human walking speed (1.0 m/s) [24]. It was expected to provide the subjects with the stimulation of walking in a typical gait speed for a person. The horses

were fitted with a saddle pad and bareback pad, and the subjects were fitted with a safety helmet and were placed sitting in a forward astride position.

Table 2. Description of horse arenas used in the study. Three arenas were used for the data collection: i) Ride on Center for Kids (ROCK) at Georgetown, TX, ii) Parsons Mounted Cavalry (PMC) at College Station, TX, and iii) Freeman Arena at College Station, TX.

Name	Size (m x m)	User
ROCK	31 x 61	Subject 1, 3
PMC	46 x 55	Subject 2
Freeman	61 x 106	Subject 4

A 20-minute HPOT session for the study consisted of two 10-minutes parts, shown in Figure 5. In the first part, the horse was led on a designated path, which is shown in Figure 6, at a steady speed (1.03 m/s) without stopping for 10 minutes. In the second part, the horse continued the same pattern, walking at the same steady pace as before, for 10 minutes, but stopping for a second every minute during which the children was holding a ring-shaped toy in his/her hand. Holding a toy in both hands prevented them from using their arms for protective purposes or to assist them in maintaining balance [25]. The rationale for dividing the session into two parts was to see the reactions to different situations. The first part focused on the rhythmical, multi-dimensional aspect of the riding experience, while the second part focused on challenging the riders balance, especially trunk control, with the abrupt changes in tempo and velocity. Figure 5 shows a rough sketch of the HPOT session.

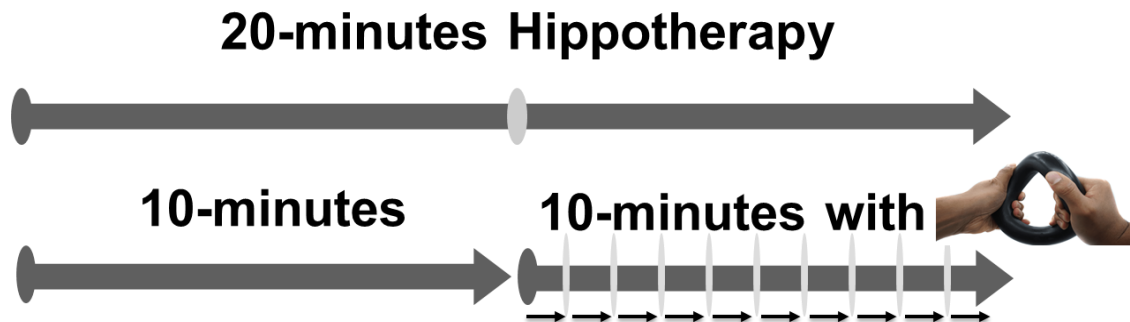


Figure 5 Rough sketch of the HPOT session

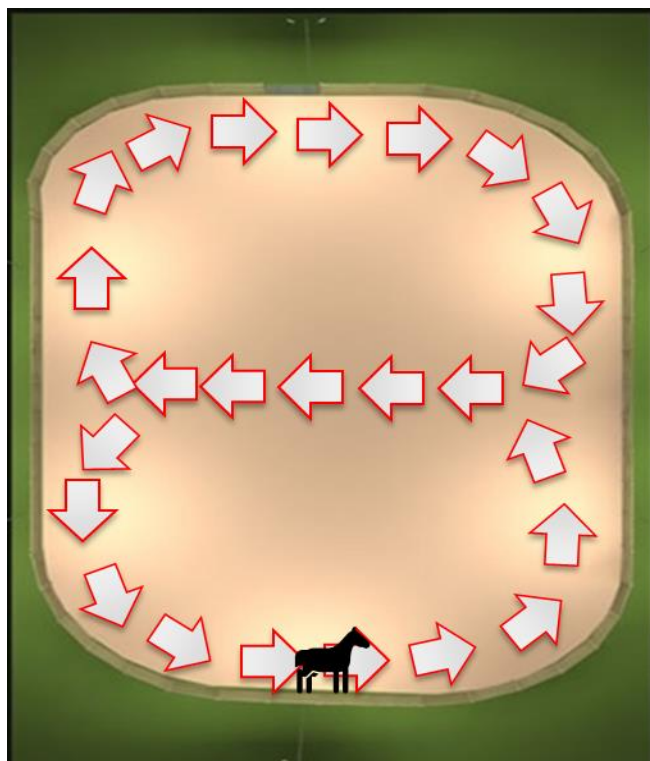


Figure 6. Trajectory of the horse in the arena during the HPOT

Although subjects were not tested by the same horse handler or in the same arena, all subjects experienced the same activities, aiming to encourage subjects to move

rhythmically with the horse while, stimulating active postural control, trunk strength, balance, and trunk/pelvic dissociation.

5.2 Functional mobility measurement

Mobility is one of the central issues for CP. The review of literature showed that Gross Motor Function Measure (GMFM) and Pediatric Evaluation of Disability Inventory (PEDI) as outcome measures are widely employed to evaluate the functional mobility of children with CP. However, those measurements might not be sensitive detecting the functional change in children with CP and they can not assume that a unit of change has the same meaning across the scale. This study used an observational research method for the subjects over a period of time. Therefore, functional mobility measurement in this study was expected to show the recognizable and measurable changes in functional mobility over a period of time.

The Timed Up and Go (TUG) and 10-Meter Walk Test (10MWT) are both valid objective measures for evaluating functional mobility over a period of time [26, 27]. These measures provide validity and clinical utility while, they are simple, quick, cost-effective and user-friendly. Functional mobility tests were conducted and administered by a therapist while the children's parents or caregivers were present. According to the subject's ability to walk and move, the first three subjects performed the TUG and the fourth subject performed the 10MWT as shown in Table 3. The fourth subject was more physically involved than the others and the 10MWT was a more suitable measurement tool for her. Both TUG and 10 MWT tests were repeated twice before HPOT and twice after HPOT.

Table 3. Functional mobility tests for subjects

Test	Subject #
Timed Up and Go	1, 2, 3
10-Meter Walk	4

5.2.1 Timed Up and Go test

TUG is a quick test used in clinical practice as an outcome measure to assess functional ambulatory mobility or dynamic balance. It is a reliable and responsive measure of dynamic balance and functional mobility for children with CP between 3 and 12 years of age [28, 29].

TUG began with the subject sitting in a chair, with arm rests. The chair was stationary when the subject moved from sitting to standing. The subject was seated in a way that hip and knee remained at 90° of flexion. A piece of tape was placed on the floor to mark a line for a distance of 3-m from the chair, with piece of vertical tape at the far end. The subject was asked to stand up, walk to end of the line on the floor, turn around, walk back to the chair, and sit down. The principles of the TUG are shown in Figure 7.

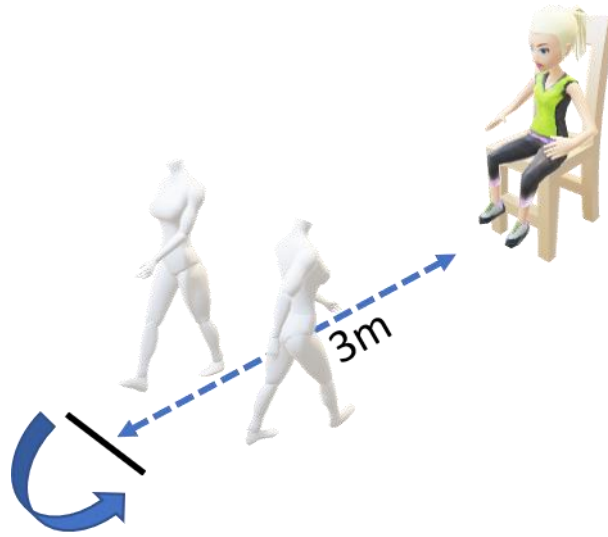


Figure 7. Principles of the timed up and go test

5.2.2 10-Meter Walk Test

The 10MWT is a performance measure used to assess walking speed in meters per second over a short distance (10-meter). This test is safe and cost-effective in CP patients with motor function disorders [27]

In the 10MWT, the subject began in standing and was allowed to use an assistive walking device (a rolling walker) because she was not able to perform the movement without the aid of the device. The test was conducted at comfortable gait speed following a verbal cue to start (begin walking). The time was measured for the intermediate 6 meters to allow for acceleration and deceleration. The principles of the 10MWT are shown in Figure 8.

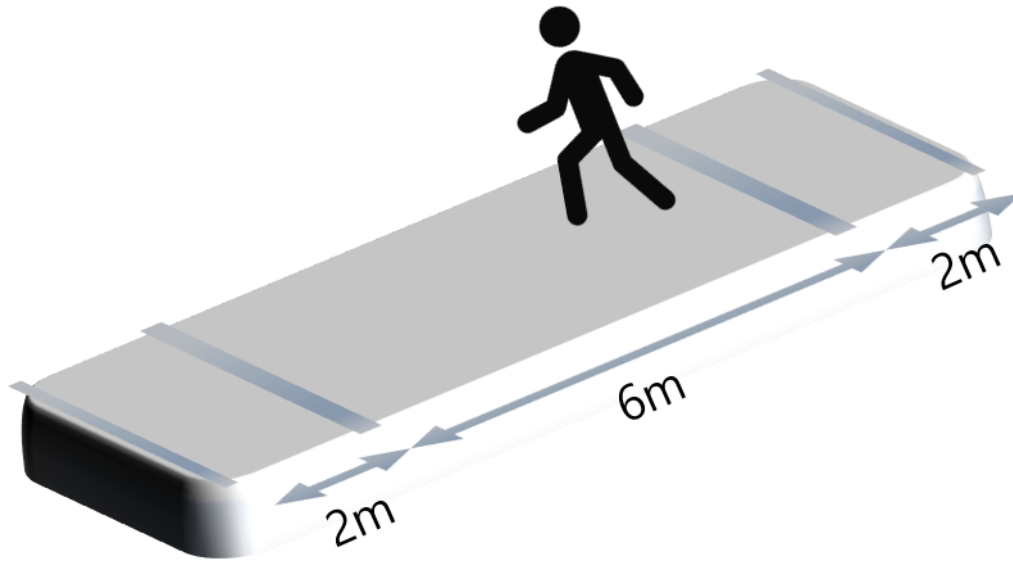


Figure 8. Principles of the 10-Meter Walk Test

5.3 IMU Calibration

An inertial measurement unit (IMU) is a tool used to measure and report a body's specific acceleration, angular velocity, and the orientation. SparkFun 9DoF Razor IMU was selected because it was small, minimizing the chance for it to distract children or for it to become uncomfortable during the session. SparkFun 9DoF Razor IMU consisted of a microprocessor, 9DoF sensor, microSD card socket, and LiPo battery charger as shown in Figure 9.

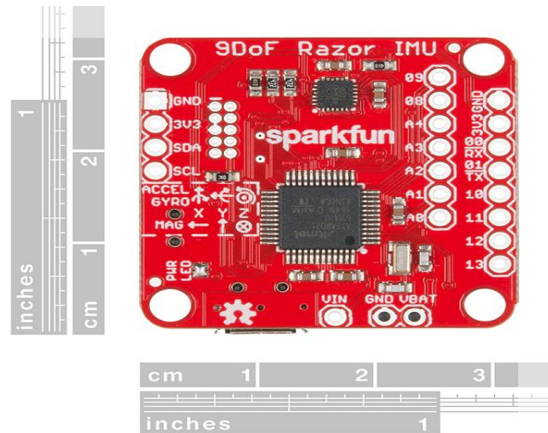


Figure 9. SparkFun 9DoF Razor. Its dimensions are 3.175 cm x 3.175 cm and weight is 8.5 gram.

"SparkFun 9DoF Razor IMU M0" by Sparkfun is licensed under CC BY 2.0.

In the HPOT, locations of 6 IMU sensors were designed to analyze the movement of children and horses: 3 sensors on the children (head, upper back, and lower back) and 3 sensors on the horses (head, back, and chest) as shown in Figure 10. The location of the children's sensors aimed to evaluate the head and trunk stability that is essential for limb movements and functional mobility [30]. The sensors placement for the horse were because:

- 1) It was the most safe and convenient place to attach to a horse.
- 2) Horse's walking movement produces a sinusoidal wave-like pattern and the researchers wanted to capture that movement if possible.

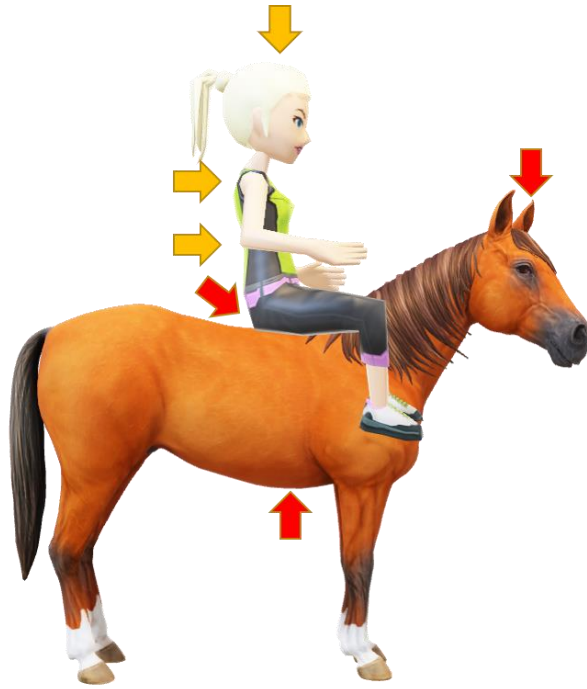


Figure 10. Location of the sensors in HPOT

The microprocessor calibrated each of acceleration, gyroscope, and magnetometer with the sampling rate at 100 Hz, which was the maximum sample rate of magnetometer. The data were logged to a microSD card.

The IMU device was programmed to collect data as soon as it was turned on. Each sensor was synchronized for same time stamps to compare with data from other sensors. In this project, the IMU devices did not use the remote communication system to limit the size of the sensor assembly. Instead, a switch box was designed and connected with all IMU devices. When the switch was pressed, the input pin of each IMU sensors turned from HIGH to LOW. This approach allowed all IMU data to display the same starting point, indicating the beginning of the therapy. Figure 11 represents The principle of time synchronization for the 6 IMU devices.

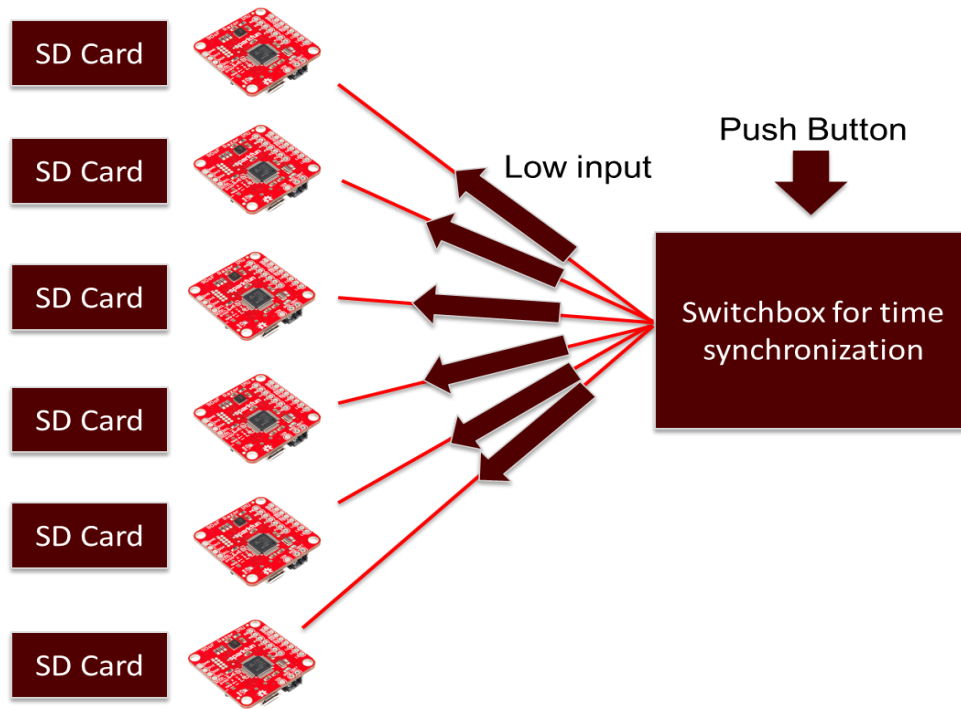


Figure 11. The principle of time synchronization for the 6 IMU devices

5.4 Data processing

5.4.1 Data trimming

The IMU data obtained during HPOT was sampled irregularly at about 11ms, and data losses happened because the data was not sampled for about 40ms each time data was logged to the SD card. For a nonuniformly sampled data set, raw data was resampled at 100Hz using interpolation of spline in conjunction in order to get a better output signal [31]. There was a need to trim the data from multiple IMU sensors. First, data before the button was pressed was deleted to have the same start time and timestamps. Second, the resampled data was divided into the first part (time instances with continuous movement) and the second part (time instances when the horse was stationary) based on the time of

recorded video and analysis of time-domain data. 360,000 continuous data for 10 min in the first part was obtained from the entire data set.

5.4.2 Data selection

Acceleration data provides changes in gravity, generating physical changes in movements of the body [32]. The use of acceleration data in the study helps figure out the change in movements of the subjects and horses during HPOT.

This pilot study is the first step for the evaluation of the interaction between the movements of horses and children with CP. In order to discover kinetic relationships during HPOT, the scope of data was narrowed. Uchiyama et al [21] reported that the movements in the Z-axis (up and down direction) have a strong correlation in the frequency spectra of human and horse walking. Data in the other directions will be analyzed for future study. Therefore, the acceleration data only in the up and down direction in this study was investigated. Data in the first part consisting of the continuous movement was used because it might include a lot of repetitive and rhythmic patterns of movement compared to the data in the second part consisting of the discontinuous movement.

When riding a horse, the human is typically sitting on the spine of the horse and is affected by the horse's back movements. The horse's back movement is directly affecting the human movement during HPOT. The horse's head and chest sensor data are also meaningful, but the horse's head and chest movements are not directly affecting the rider's movement compared to the horse's back movement. Therefore, the horse's back acceleration data was selected for the kinetic relationship between horse and human during

HPOT. The horse's head and chest acceleration data will be examined in the future. For those reasons, this study planned to use IMU data in the up and down direction in the first part. Besides, the horse's back acceleration data was selected as the representation of the horse's movement for the kinetic relationship.

5.4.3 Fast Fourier Transform

Two signal processing methods were used to analyze the data from the IMU sensors. Fast Fourier Transform (FFT) was used to convert a signal into its corresponding frequency domain to analyze variations in data, such as an event over a period of time. FFT produced the frequencies at which the high peaks of magnitude converted by FFT were generated [33]. Through Fast Fourier Transform, repetitive pattern of each signal can be displayed, and specific frequencies would be dominant.

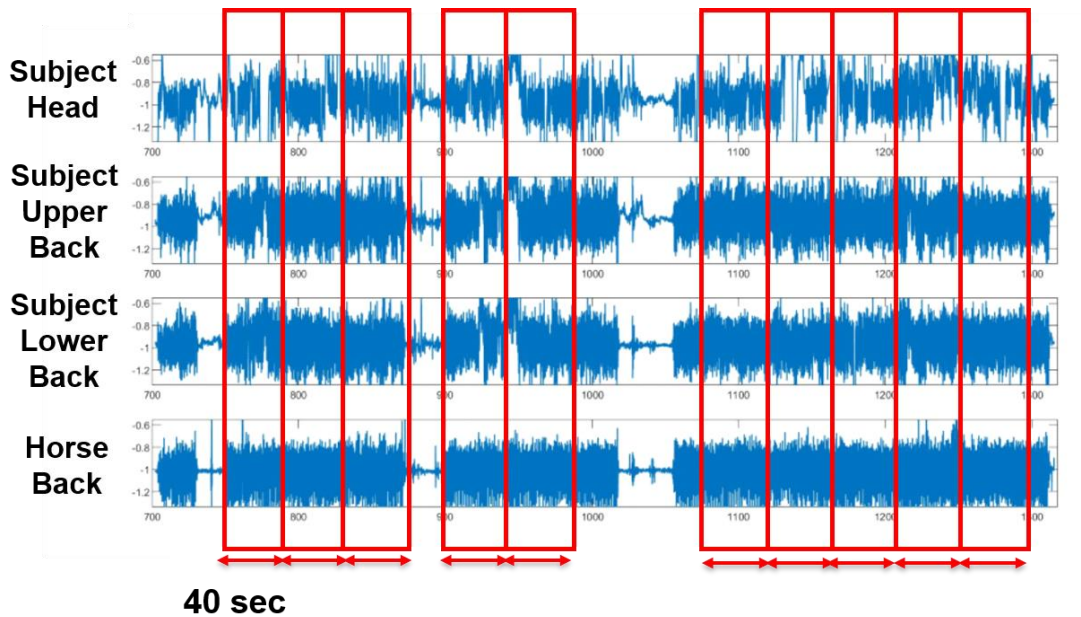


Figure 12. Example of calculation process for the frequency error between signals of subject and horse's back

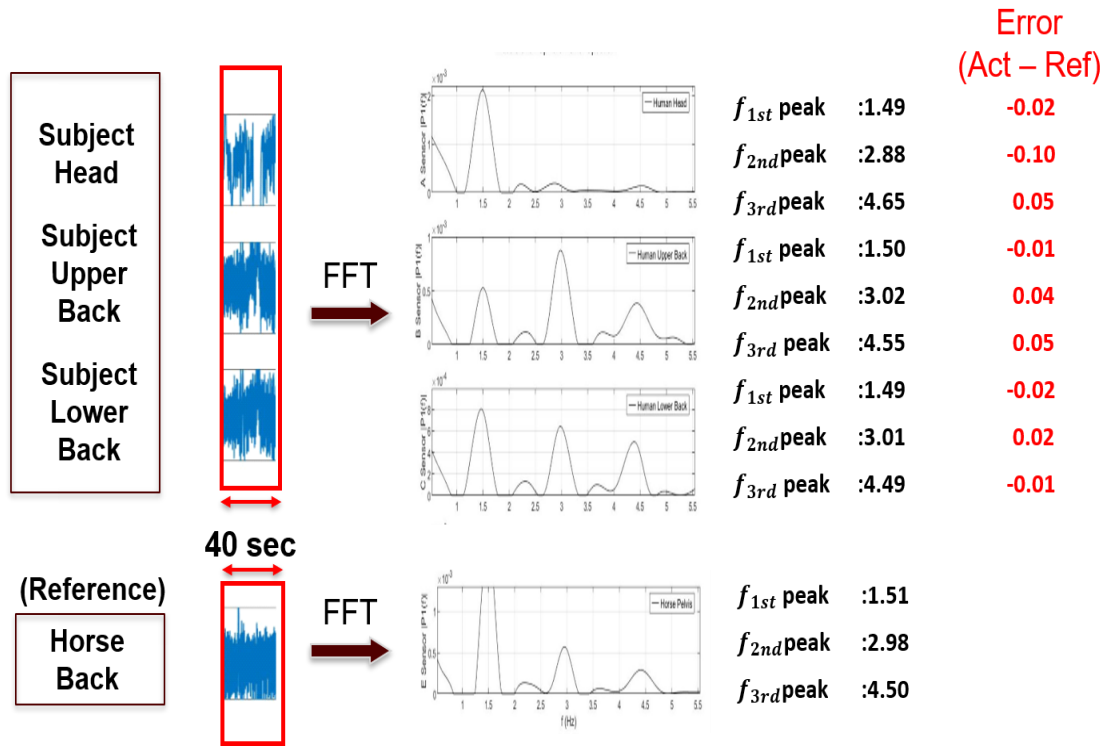


Figure 12 Continued.

For accurate analysis of correlation in frequency between the horse's back and subject's movements, the frequency error between those movements was calculated. Figure 12 shows how to calculate the frequency error between signals of the subject and the horse's back. First, each 10-minutes data was split into 10 data with 40sec, which consisted of a continuous movement without a stop or noise. Second, each acceleration data with the same timestamps was converted into its corresponding frequency domain by FFT. Then the first three frequency peaks of each acceleration data were found. The frequency peaks of the acceleration data of the subject were compared with the frequency peaks of the acceleration data of horse's back to produce error. The set of error within sessions was

calculated into root mean square error. This method aimed to observe the changes in frequency peaks of acceleration data as the number of sessions increased.

5.4.4 Correlation by a time shift

Correlation computed a measure of similarity between two inputs. Any time delay between the signals was accounted for with an added time shift. In this study, all signals pertaining to the subject were processed with respect to signal from the horse's back movement. The correlation method investigates the relationship between two random variables. The correlation coefficient is the statistical measure that is going to allow us to quantify the degree of correlation between two random variables A and B [34].

$$\rho_{AB} = Corr(A, B) = \frac{Cov(A, B)}{\sigma_A \sigma_B} = \frac{\sigma_{AB}}{\sigma_A \sigma_B}$$

where σ_{AB} , σ_A , and σ_B are the square root of covariance of A and B, and the standard deviations of A, and B respectively.

To find the time delay, correlation was modified by applying a time shift. The fixed signal was correlated with another one moved by some elements to the left and to the right. In this study, the signal from the back of a horse was set as the fixed one and the signals from subjects are moved to the left and to the right. This method is the same as the principle of cross-correlation. In this method, the highest correlation values are shown at positive time values, which means the signals from the subject are shifted to the right. In other words, the signals from the subject follow the signal from the horse and the movement of the back of the horse.

6. RESULT AND DISCUSSION

6.1 Functional mobility test

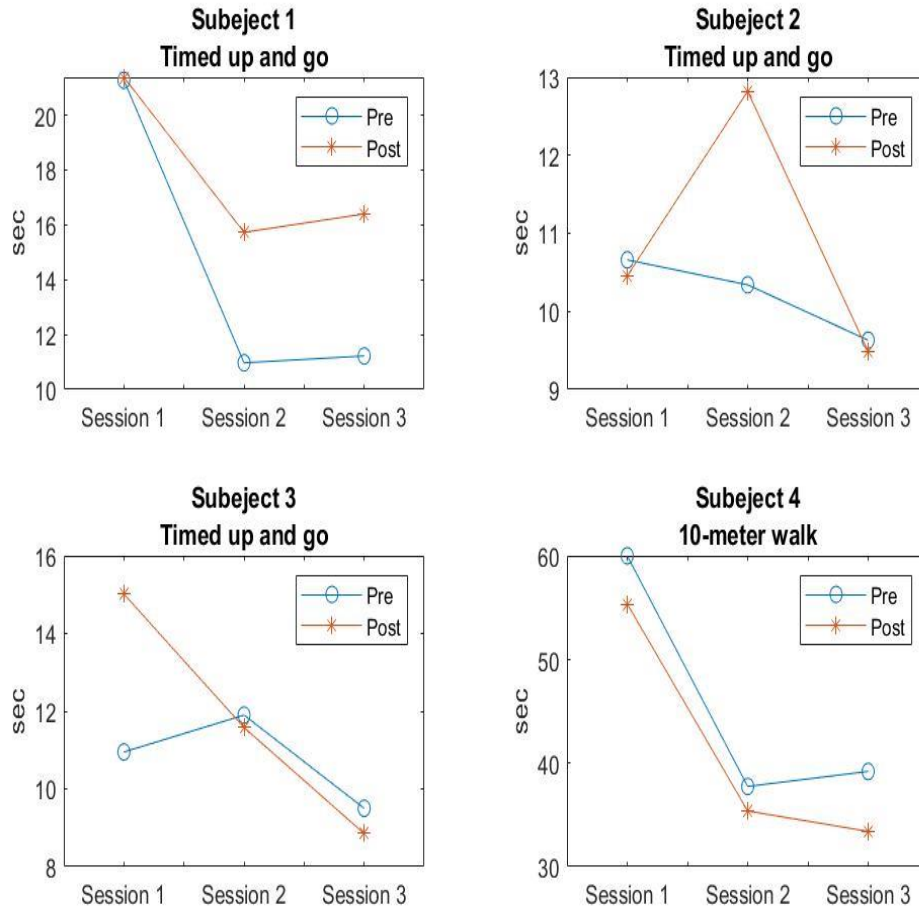


Figure 13. The outcomes of functional mobility tests for each subject

Comparison of results of the functional mobility test between before and after HPOT was not meaningful because children with CP were entirely tired and fatigued by the end of the experiment and the results of functional mobility tests might vary between before and after HPOT. Considering the fatigue levels of the subjects, the results before HPOT

and after HPOT were not compared. In Figure 13, all 4 subjects in the last session resulted in better improvement in functional mobility compared to the first session. Especially, in case of the subject 4, there were around 20 seconds decrease in 10-meter walk test between the first and last sessions.

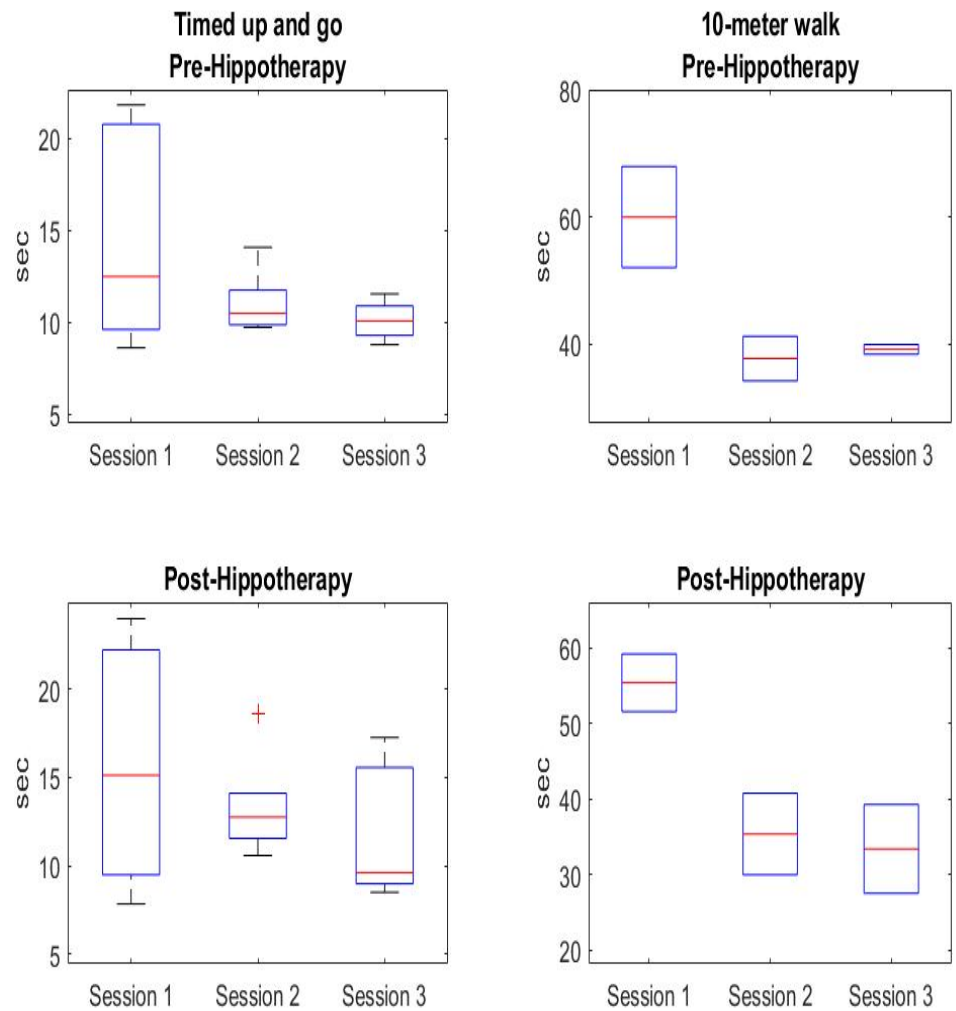


Figure 14. Boxplot of outcomes of functional mobility tests

For a better understanding of the results of the functional mobility tests, a box plot for the outcomes of the functional mobility tests was made depending on the type of test and before and after intervention. Observation has shown that the mean values of all subjects apparently dropped as the number of sessions increased. A range of variations in the results of the tests before HPOT decreased as the number of sessions increased. A range of variations in results of the tests after HPOT is not consistent rather is increasing over sessions. It might be explained that the fatigue levels of the subjects led to inconsistent variation of the outcomes. Despite the factor affecting the results, there is a strong trend that the progress of HPOT sessions resulted in improvements in functional mobility. The results show that there was a decrease in the mean value of outcomes of functional mobility tests as therapy progressed. Also, a comparison in mean value and range of variation between the first and last sessions supports the hypothesis of this study that there would be positive changes in the functional mobility of children with CP as the therapy progressed.

6.2 Fast Fourier Transformation

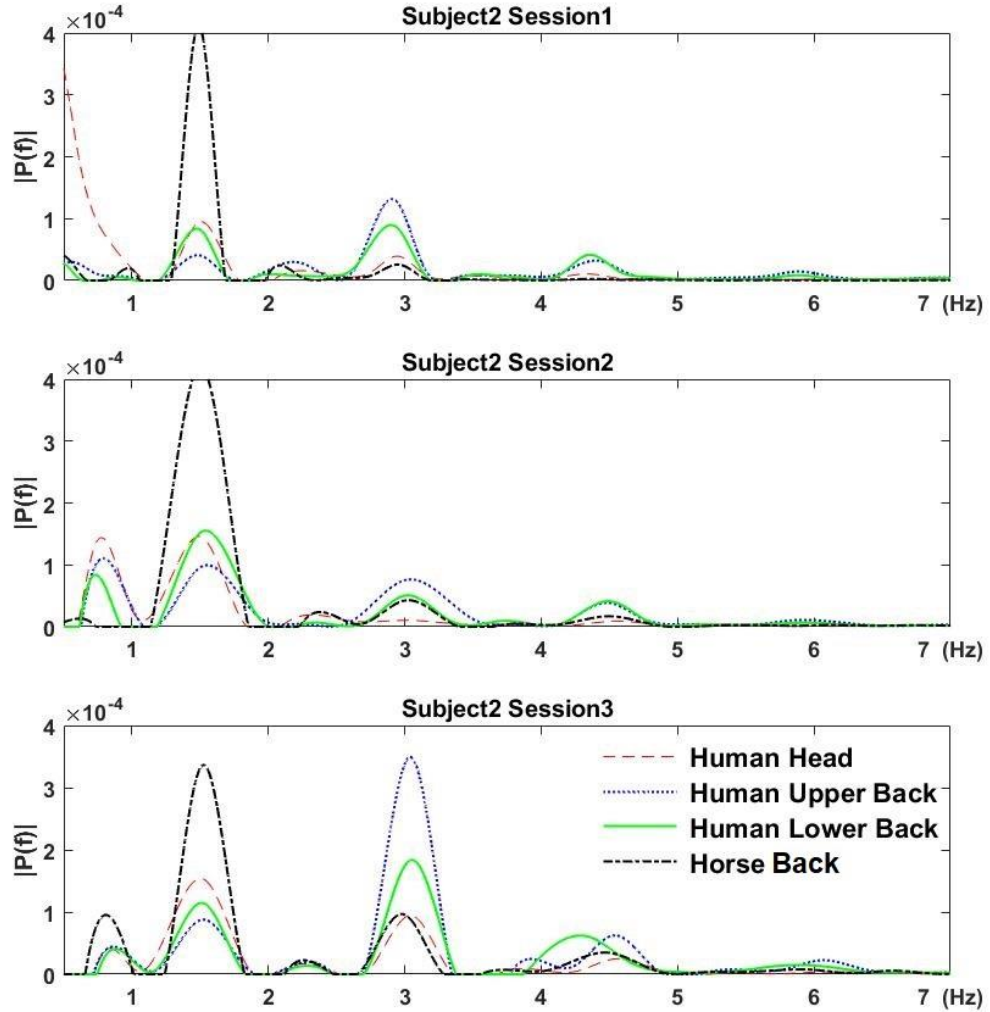


Figure 15. Spectral patterns of movements of subject2 and horse's back in the up and down direction during therapy each session

The acceleration spectra of subject 2 and horse are shown in Figure 15. The direction of acceleration used for data analysis was up and down (Z-axis). In the study, the frequency of the acceleration of the movements of subjects and horses was calculated by

FFT. Frequency peaks of movements of subjects and horse's back were compared to find the similarity between those of subjects and horse's back. The frequency peaks of subject 2's movement and horse's back movement were 1.5, 3, and 4.5 Hz. As shown in Figure 15, the frequency peaks of movement of subject 2 corresponded with those of the movement of horse's back during HPOT.

Figure 16 represents the average spectral patterns of movements of all subjects and horse's back. Like the patterns shown in Figure 15, average spectral patterns of

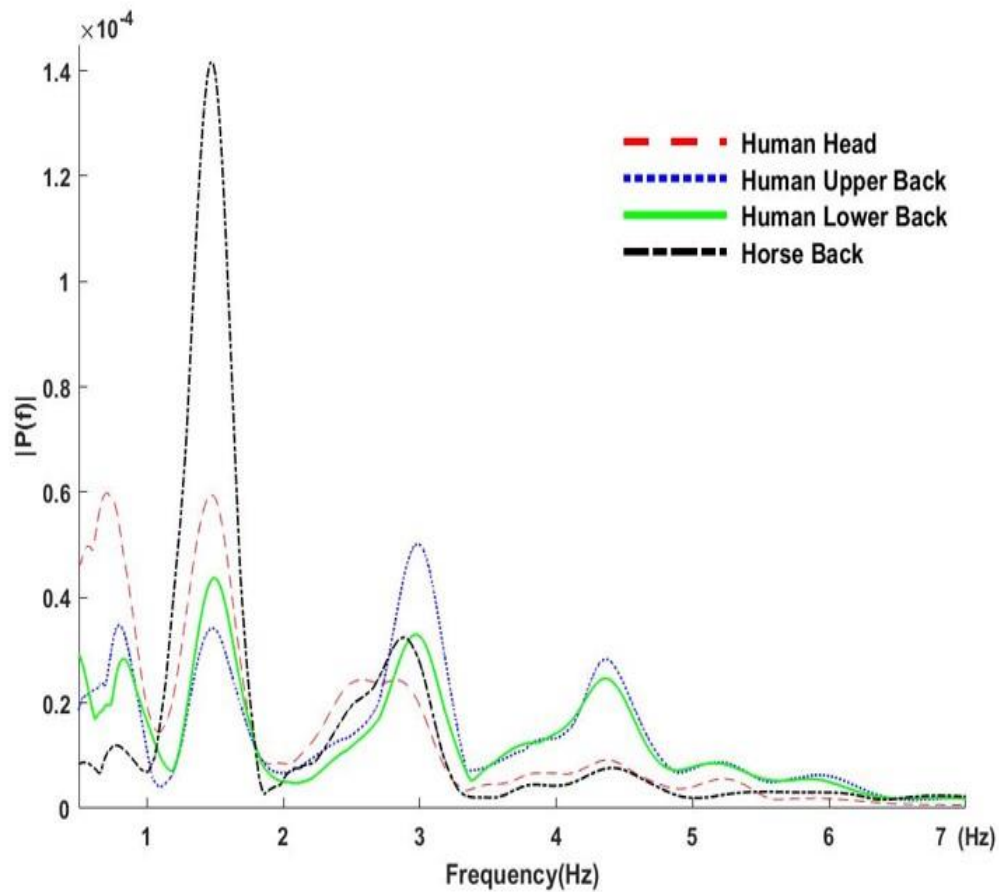


Figure 16. Average spectral patterns of movements of all subject and horse's back in the up and down direction

movements of all subjects and horse's back show the same frequency peaks and similar patterns. The power spectra of acceleration data of the horse and subjects in the up and down direction were strong at the low frequency and were weak at the high frequency. Thus, 3 frequency peaks of movements of all subject and horse were noticeable. Observation has shown that the frequency peaks of movements of all subjects corresponded with those of movement of horse's back during HPOT at 1.5, 3, and 4.5 Hz. There might be a close correlation between the movements of subjects and horses during therapy.

As shown in 5.3.2, the frequency error calculation was done to observe the changes in frequency peaks of acceleration data as the number of the sessions increased. Figure 17 exhibits the boxplot of frequency error between movements of the subjects and horses each session. It was obvious that frequency error between movements of the subjects and horse's back decreased as the number of sessions increased. The mean values and the range of variation in the frequency error dropped significantly as HPOT progressed. The dominant frequencies of the movement of children with CP synchronized with those of horses. The boxplot of frequency error between movements of the subjects and horses each session provides stronger evidence to support the hypothesis of study that the movements of children and horses during the therapy would be correlated as HPOT progresses.

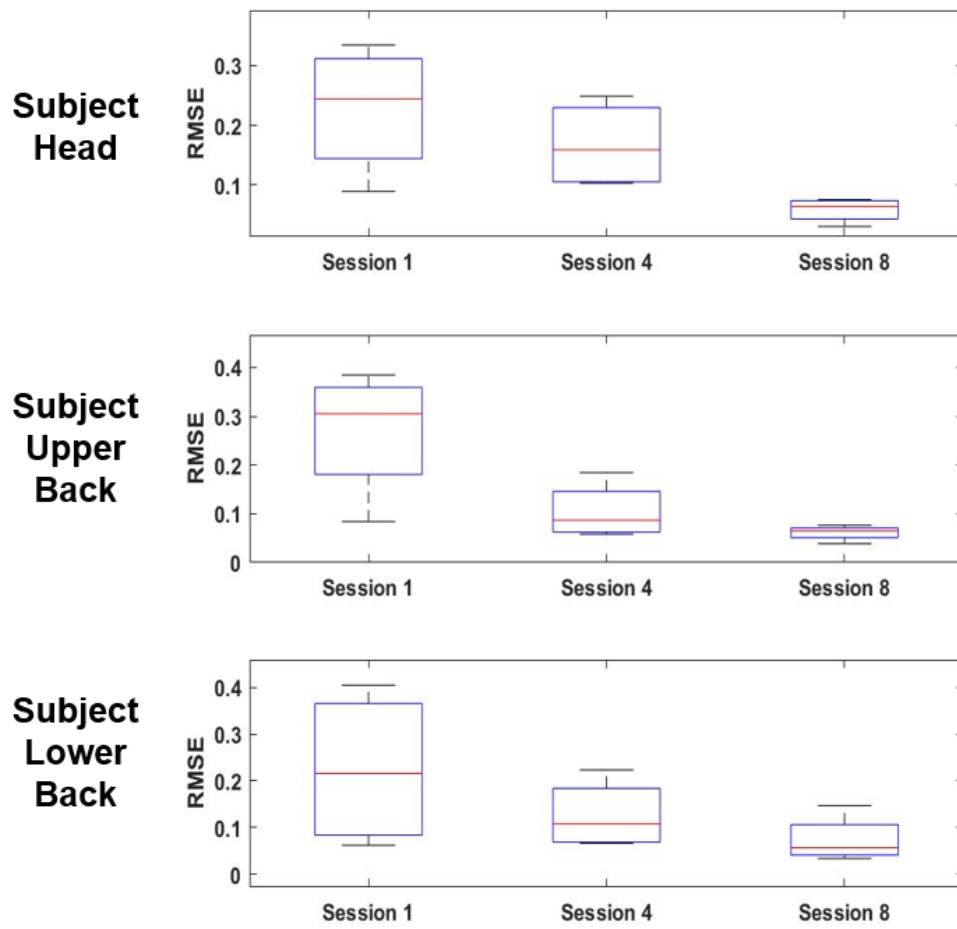


Figure 17. The boxplot of frequency error between movements of the subjects and horses each session

6.3 Correlation by a time shift

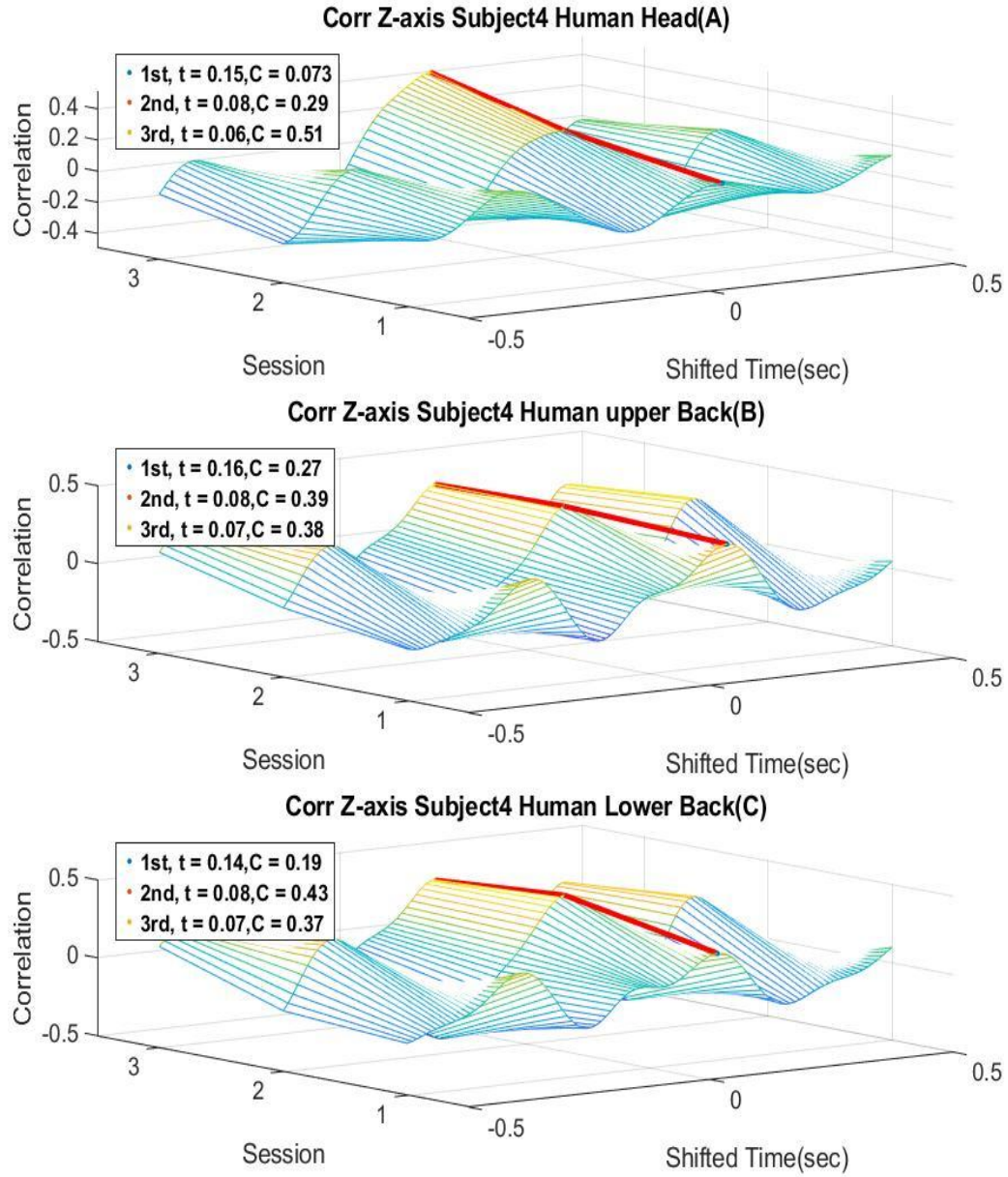


Figure 18. Correlation between horse's back and subject by a time shift for the acceleration in the up and down direction of subject 4

To evaluate the time delay between two signals, the correlation by applying a time shift in MATLAB was used for the acceleration in the up and down direction of subjects 4. The highest correlation values were shown at positive time values, which means the signals from the subject followed the signal from the horse's back. Figure 18 shows the correlation between the horse's back and subject by a time shift for the acceleration in the up and down direction of subject 4. There were no significant changes in time delay at which the highest correlation value was generated over sessions. However, there was an increase in the highest correlation between the horse's back and the subject as therapy progressed. The more synchronization between the movements of the horse's back and subject during HPOT happened over sessions at a specific time delay.

There was a need for analysis of data for all subjects thus box plot of the highest correlation between movements of all subjects and horse's back during HPOT and time delay by cross-correlation method for acceleration in the up and down direction was made. Figure 19 exhibits that the correlation values of all subject sensors with horse's back increased as HPOT progressed. The time delay values of all subject sensors with horse's back neither increased nor decreased over sessions. Despite inconsistent time delay, the time delay was positive at the highest correlation value and it represented the subject's signals followed the back signal. As the number of sessions increased, the mean values in the correlation value increased while the range of variation in the correlation value was not consistent.

The result explains the trend that continued HPOT allowed the children with CP to become familiar with the horse's movement over time. There was a trend the children's

movement synchronized with the horse's movement over sessions. Positive interaction between the movements of children with CP and a horse occurred during HPOT and improved over sessions.

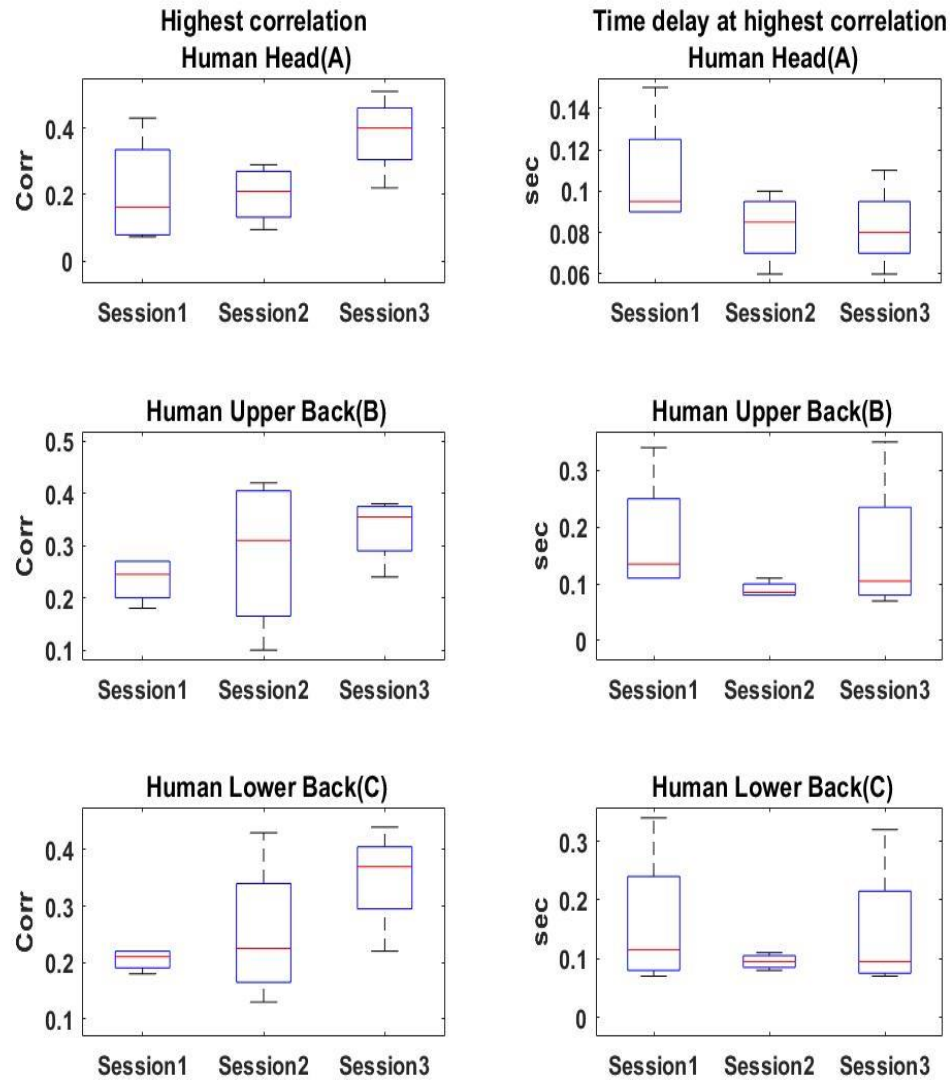


Figure 19. Box plot of highest correlation between movements of all subjects and horse's back during HPOT and time delay by cross-correlation method for acceleration in the up and down direction

7. FUTURE WORK

This pilot study is the first step for evaluation of the interaction between children with CP and horses during HPOT in terms of kinetics. Even though some noticeable trends were discovered in the study, this pilot study has the limited sample size resulting from difficulty with recruitment for children with CP for the study in one place. In this study, there were differences in ages and levels of severity among the subjects, and it might cast doubt on the reliability of the results for the study. Therefore, large number of subjects and data collection sessions will be included for the future work.

As mentioned in the research goal and objective, there was a limited scope of data selection. Future work includes analyzing acceleration data in the forward and side direction, the second part data (time instances when the horse was stationary), and data of horse's head and chest. There was an interesting result of correlation for acceleration data in the side direction. Figure 20 shows the higher correlation values than the result of correlation for acceleration in the up and down direction and consistent time delay. Therefore, it is worth attempting to examine the different data that was not used in this pilot study.

Although the study provides the positive effects of HPOT on functional mobility of children with CP and positive interaction during HPOT, the causality between improvements in functional mobility and positive interaction between the movements of children with CP and horse can not be explained using results in this study. To figure out the causality, two different environments would be designed. One is riding a horse with

interaction and another is riding a horse without interaction. Those two situations help understand the effect of interaction on the improvements in functional mobility.

There will be an evaluation of the frequency difference in normal walking between children with CP before and after HPOT. Functional mobility measurement is reliable and recognizable but functional mobility needs to be analyzed in changes in the walking frequency. More studies are required to determine the impact of HPOT on children with CP.

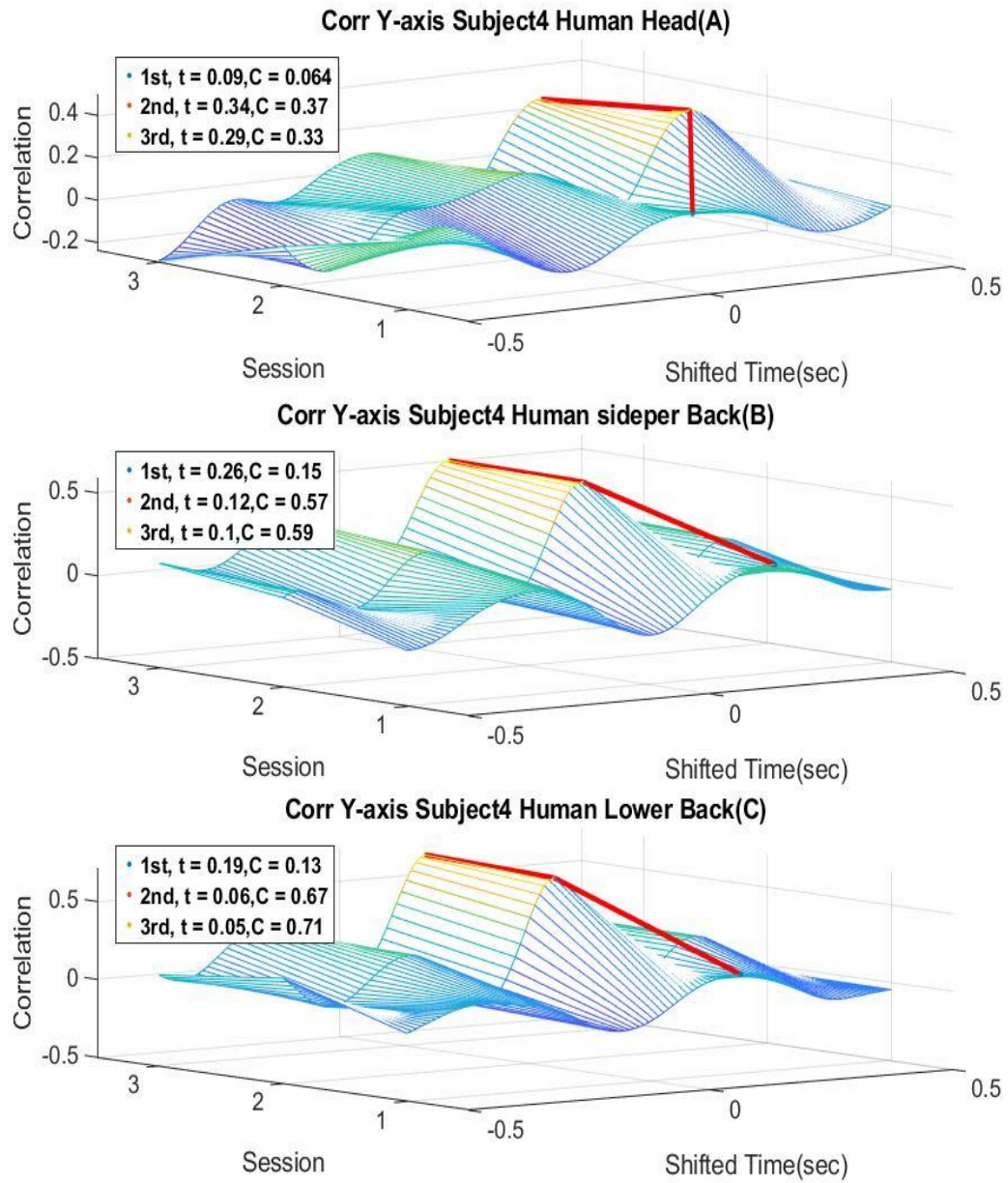


Figure 20. Correlation between horse's back and subject by a time shift for the acceleration in the side direction of the subject

8. CONCLUSION OF THESIS

This study investigated how the improvement in functional mobility is linked with the interaction between children with CP and horses during HPOT. Observation showed that HPOT might have led to improvements in the functional mobility of the children in the study and there was a positive synchronization between movements of the children with CP and horse during HPOT sessions. There was a noticeable trend that outcomes of functional mobility test and synchronizations between movements of children with CP and horse improved over time. Despite the limited scope of the pilot study, the results obtained from the experiment support the benefits of HPOT.

Park et al [16] demonstrated the positive effects of HPOT on gross motor function and functional performance of children with CP. In this study, although different functional mobility measurement was used, the improvements in functional mobility in children with CP through HPOT were observed. Also, Uchiyama et al [21] examined the similarity between the accelerations of the horse and human gaits, indicating that horse riding could provide the motor input received from walking. This study showed the trend that children with CP were able to produce a positive reaction to the input from horse walking during HPOT.

HPOT has the potential to be a valuable treatment intervention that maximizes the functional mobility of children with CP. HPOT can be referred to as the interaction with a horse. This study is expected to lay the foundation for a better understanding of the interaction between patients and horses. The synchronization between the patient's and the horse's kinetics implies a positive response to the therapy. If successful, therapists can use

the synchronization metrics, proposed in the study, to justify any improvement seen in the patients. It is hoped that designing therapeutic activities that target these synchronization metrics can result in accelerated rehabilitation.

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